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TRANSFERRING BEST PRACTICE FROM UNDERGRADUATE PRACTICAL TEACHING TO SECONDARY SCHOOLS: THE DYNAMIC LABORATORY MANUAL

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Abstract: Pre-laboratory work has been shown to be an effective investment at undergraduate level in chemistry at the University of Bristol. A Dynamic Laboratory Manual (DLM) has been developed to allow undergraduate students to rehearse practicals using virtual experiments, video clips and a range of assessment support. The DLM has been shown to be highly successful in its goals. In this paper we describe the development and implementation of a DLM appropriate to post-16 students at school or college which also has applications in teacher training courses. First results from evaluation are presented which show an improvement in practical skill and cognition.

Zusammenfassung: "Pre-Arbeit" im Labor hat sich gezeigt, auf eine wirksame Investitionen auf Undergraduate-Ebene in Chemie an der Universität von Bristol, sehr effectiv und erfolgreich. Eine dynamische Laboratory Manual (DLM) wurde entwickelt, um Studenten zu problem Praktika mit virtuellen Experimenten, Video-Clips und eine Reihe von Bewertung zum unterstützen. Die DLM hat sich gezeigt sehr erfolgreich in ihrer Ziele. In diesem Beitrag beschreiben wir die Entwicklung und Umsetzung einer DLM, nach eine Studie in dem 16 Schüler einer Schule oder Hochschule angewendet haben. . Erste Ergebnisse der Bewertung zeigen eine Verbesserung der praktischen Fähigkeiten und Wahrnehmungen.

Keywords: Dynamic Laboratory Manual, practical rehearsal, e-learning, multimedia

1. Introduction

Software, called a Dynamic Laboratory Manual (DLM), has been developed to support practical chemistry teaching for undergraduate chemists at the School of Chemistry at the University of Bristol. [1]. It has been shown that the DLM methodology has significantly enhanced both practical skills and chemistry cognition. Best practice derived from the undergraduate DLM has been adapted to support school students taking pre-university courses and is playing a major role in the teaching of practical skills for the UK's trainee graduate chemistry teachers. The distribution of software to all Postgraduate Certificate of Education (PGCE) student teachers within the UK has been sponsored by the Royal Society of Chemistry (RSC) and the pharmaceutical company Pfizer in a collaborative project called Discover Chemistry [2,3]. The project, which is to last for two cohorts of trainee chemistry teachers will impact around 1300 new chemistry teachers.

2. Developmental History

Bristol's School of Chemistry is home to the UK's Centre for Excellence in Teaching and Learning in practical chemistry. Funded by the Higher Education Funding Council for England (HEFCE) [4], the project, named Bristol ChemLabS [5], developed groundbreaking best practice in undergraduate practical work. The software package, called the Dynamic Laboratory Manual (DLM) [6] is an

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interactive, web-based laboratory manual, which replaces the more traditional paper lab manuals for the first three years of their chemistry degree. The DLM has been developed by university academic and technical staff in association with the university 'spin out' company Learning Science Ltd [7]. The premise of the investment of half million pounds in the Bristol ChemLabS project was that students will gain much more from the laboratory experience if they know what they are doing and why they are doing it. The students own pre-laboratory preparation is naturally the key to achieving this [8]. When left to their own ends few students carry out their own unstructured preparation for lab classes. In their defense, it is hard to rehearse practicals apart from reading through laboratory scripts. Moving the majority of practical-related work performed outside the laboratory to *before* rather than *after* the practical class is superior for a number of reasons; it ensures that students are much better prepared, they understand the point of the practical work they are performing, they can consider the practical skills they are developing and are more confident to make use of the academic staff and postgraduate demonstrators present during the lab time, they make more use of the time in the laboratory (an expensive resource in any setting). However, the students need to be able to rehearse the practical for any investment in pre-lab time to be truly effective. The department's School Teacher Fellow [9] present during the development of the DLM immediately saw the potential to make better use of the limited time given over to practical work in pre-university (Advanced Subsidiary 'AS' Level, Advanced 'A' Level and International Baccalaureate, IB) courses. The materials written for the schools' version of the resource needed to be focused on the appropriate laboratory skills relevant to schools and colleges. However, adapting the basic idea was only possible given the range of personnel available at Bristol. The software covering the practical skill development for the first year of the two year pre-university courses has been in circulation since September 2008 and work on the second year will be complete by May 2009. From this sprang the potential to use the software package within teacher training courses. The LabSkills software is available at Science Learning Centres within England [10] for its incorporation into appropriate continued professional development (CPD) courses for chemistry teachers. In the UK not all trainee chemistry teachers are chemistry graduates so they cannot be expected to know all the practical techniques and related tools that they need to teach. Hence, the LabSkills software could play a significant role in the training of the graduate scientists who are embarked on the one year PGCE teacher training programmes in the university education departments. First, to support their own development of the understanding of the practical work covered at pre-university and second, to use to help deliver this work during their teaching practices and subsequently during their first year of employment in schools and colleges.

3. What is the software? What does it do?

The AS Chemistry LabSkills DLM [11] is the result of expertise in virtual learning and practical science teaching in a format that has the potential to change radically the way scientific skills are taught in schools. The resource contains over one hundred interactive tools that enable students to explore experimental chemistry before they reach the laboratory. It covers core practical skills and techniques (Table 1) using innovative and highly effective materials and methods.

There are twelve self-contained modules covering the entire range of laboratory techniques commonly used in UK pre-university chemistry courses. Each of the modules contains a mix of simulations, videos, safety resources and multiple choice tests. Seven additional modules consider core laboratory competencies covering basic skills, lab calculations, tests and observations.

The user can prepare for practical classes in a safe e-learning environment, using the virtual experiments. They learn by exploring, questioning and making mistakes that does not cost money in broken glassware and spilt chemicals, take part in scientific decision making, check their understanding and progress and revise commonly examined skills, techniques and concepts and explore different approaches whilst correcting mistakes along the way. The result, based on trials, is that users at all levels come to the laboratory with a greater understanding of the practical work and what they are trying to achieve. In addition they achieve far more in the laboratory, in terms of practical skills mastered and cognition of the subject.

The resources in AS Chemistry LabSkills also provide an excellent opportunity for new teachers to familiarise themselves with the common errors that students make in the laboratory and a chance to increase their own confidence in setting up and performing the experiments typically found at this level. The simulations allow the usual student errors to be programmed in so when the user makes them, warning messages appear explaining the error and then allows the user to retry. For example in working through the set up of a distillation apparatus, the mistakes in the positioning of the thermometer, the correct size of flask, correct heating rates and the direction of the flow of water are amongst the errors that the authors have experienced over many years of teaching and have all been addressed. From the point of its inception, secondary level teachers were involved in the design. At an early stage a teacher forum was established to review the material. Once in a more complete format, the software was trialled in a variety of schools to obtain feedback from both teachers and students. The comments were then acted upon. One such comment from students was a request for a glossary of chemistry equipment. The package was then given to Edexcell, one of the UK's main examination boards, for their detailed feedback. This major examination board has now endorsed its use for their examination centres. The reviewer commented 'I judged the animations to be generally good with some excellent, e.g. carrying out a recrystallisation. Most of the video sequences were good with some excellent. In particular the determination of melting point video allowing the students to read off the temperatures was outstanding.' [12]

Section	**Topics**
Laboratory techniques	Titration, Reflux, Distillation, Recrystallisation, Solvent extraction Filtration, Melting point, Calorimetry-in solution, Calorimetry-combustion, Collection of a gas
Basic skills	Preparing solutions Weights and measures
Laboratory calculations	Errors and significant figures Stoichiometry and yield Quantities and concentration
Tests and observations	Tests for inorganic ions Tests for organic functional groups
Instrumental techniques	Mass spectrometry IR spectroscopy

Table 1. *Laboratory techniques and skills covered within AS Chemistry LabSkills*

Trainee teachers can also make use of the DLM in many ways in schools to make better use of valuable lab time. Before preparing for a practical ('Prelab') **s**tudents can be directed to work through specific sections in the resource in the lead up to practical work. This supported self-study may be used as homework. School students can submit printed test results from the questions. A networked version of LabSkills also allows results to be viewed electronically on the school's virtual learning environment (VLE) should they have one operating. This also gives the trainee teachers the opportunity to explore this IT tool that is becoming more commonly found in UK schools but, according to many comments received, not so often used to its full potential

"LabSkills could revolutionise the way practical chemistry is approached in schools. By encouraging students to prepare for their experimental work, it will help them to view practical chemistry as something much more than a recipe-following exercise."

Dr Tony Wood, Worldwide Head of Medicinal Chemistry, Pfizer Global R&D

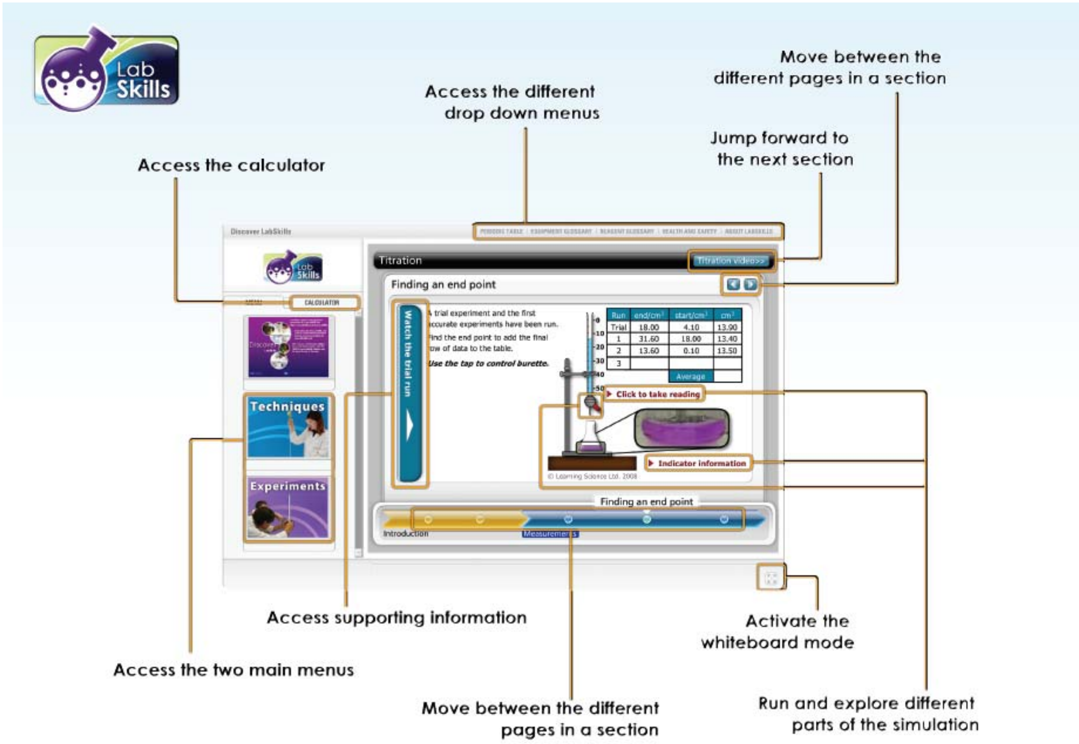

Figure 1. *A description of the key features of AS Chemistry LabSkills*

The second main section of the LabSkills DLM gives an introduction to eleven widely performed experiments covering preparative, qualitative and quantitative practicals common to most exam boards. These will support and not replace teachers' own practical scripts. The experiments include the oxidation of alcohols, enthalpy of neutralisation and of combustion, preparation of an organic acid, redox titration and identification of unknowns amongst others. Interactive images for each experiment are broken down with information on background and context, experimental procedure and observation opportunities. Importantly there is a great emphasis on safety and good laboratory practice. Each practical technique contains interactive simulations, which are intuitive and media-rich. These provide multiple opportunities to explore techniques through trial and error, addressing all common student mistakes with questioning, hints and feedback. They allow students to understand the reasons for setting up equipment correctly, the optimising of experimental conditions and allows for the visualisation of molecular behaviour during instrumental analysis. Short video clips showing the latest equipment being used and providing a step-by-step breakdown of each technique with brief notes are included. Some techniques are best illustrated by video and users find this very useful to have a clear idea of what they will need to do in the laboratory whether demonstrating or giving class students direction. Some have very limited experience of general laboratory apparatus and glassware. Seeing how to use equipment and learning what a particular set of apparatus is use for leads to increased confidence. By raising confidence, students progress further through the practical work and as a result have a much better idea of the chemistry that is being explored in the experiment that it uses.

"Practical skills are crucial for success in science courses. This revolutionary resource can give students a chance to explore, question things and make mistakes before and after lessons, meaning they can use their valuable laboratory time much more constructively and efficiently. It's really important for students to be able to learn by doing and to be able to make mistakes from which they improve their understanding."

Scientist and UK TV broadcaster Kathy Sykes, Professor for the Public Understanding of Science

There are multiple choice examination questions related to the experiments and relevant theory within the software. Some questions include multiple correct answers rather than the more usual one correct with three or four distracters. Feedback for incorrect answers is provided. Review options are available as they are for the tests on techniques. Some exercises have questions and worked examples with interactive hints and feedback, understanding chemical tests and the appropriate choice of equipment and balancing equations and using mathematics within chemistry. Additional resources, via drop down menus consist of an equipment glossary, a reagent glossary, health and Safety – the general rules for laboratory health and safety, a periodic table and a calculator.

A whiteboard option allows the screen size to be maximised so that interactive elements can be used for whole class reviews and group discussion and the software may be run on whiteboards in the laboratory as an aide memoire during the practical class.

Preliminary Evaluation

We have addressed evaluation in three ways; in use within schools, within outreach activity at the school of chemistry and with trainee chemistry teachers.

‘We now have LabSkills up and running and fully integrated with our VLE. We have used it in preparation for a coursework assessment involving titration and all students found it easy to follow through the materials and complete the test at the end. The results of tests were recorded by the VLE so it was easy for me to see which students had not done the preparation work and which students still required more help. As a result of this more focused intervention strategy all students were able to score highly on the assessment and unlike previous years none will have to repeat the ordeal. We now plan to match up the LabSkills modules with other parts of our course and make it a more regular part of our practice.’

Alan Francis Head of Chemistry Gordano School North Somerset UK

As part of Bristol ChemLabS outreach programme [13, 14] a group of 29 Post 16 students from a large state school were invited in the department. With the cooperation of the chemistry teacher the group were split into pairs and half of the groups were given access to AS Chemistry LabSkills over a week in advance whilst the other group were not. The teacher was asked to ensure that each group was of similar intelligence.

On arrival at the school of Chemistry the students were given an electronic pre-event questionnaire. The students were then given a two and a half hour practical exercise to extract caffeine from tea leaves. The extraction involved using electric heating mantles, Buchner filtration, solvent extraction and rotary evaporation. The students were supervised throughout by postgraduate chemists vey experienced in working with school aged students and the School Teacher Fellow. The accompanying teachers were also present. During the practical session the students were given a paper questionnaire to complete. After the lunch break the students had a post event questionnaire and a talk on the Chemistry of Toothpaste and a lecture demonstration on the gases in the air entitled A Pollutant’s Tale’ [15].

The analysis of the electronic feedback to the twelve questions about aspects of experimental techniques that were involved in the day’s practical activity showed that those that had prior to access to LabSkills gave 89% correct responses against 26% who did not have access.

In response to a Likert style statement ‘I’d like to use more computer-based resources to help me prepare for lessons and revise for exams’ 55% agreed, 24% expressed no , preference, 10% were unsure and 10% disagreed.

The analysis of the free responses (sometimes more than one answer for each question) to the paper questionnaires given out to students during the practicals gave telling feedback.

Question 1. Do you like doing practicals?

In response 82% said yes, 12% did not explicitly say and 6% said ‘sometimes’. When asked why they like to do practicals, the most common responses were ‘fun/interesting/ enjoyable’ (30%), ‘Strengthens understanding/links theory/makes relevant’ (39%) and the variety of responses ‘exciting’ , ‘stressful’, ‘learn at first hand’, ‘sense of achievement’ and ‘less writing/watching powerpoint’ were equally distributed.

Question 2. Would you prefer to do more practical work or less?

94% wanted more practical work and 6% the same amount. Comments received were ‘[there is a] good sense of achievement when finished' and 'Appreciate we have to learn why we do the experiment before we do it if we want to learn as much as we can from it.'

Question 3. Would you benefit from knowing more about experiments before doing them in the lab?

88% responded positively and 12% were not sure. When asked to explain their answer 69% said it helps with ‘understanding’, 15% stated that it ‘makes experiments easier’ which 8% each saying that it ‘helps with theory’ and ‘safety’. Comments included ‘'…. I can concentrate on the process and reactions rather than the order of equipment', 'Often you do an experiment with little awareness of the real chemistry going on' , 'Often I don't understand what we are supposed to be finding out' and '[I] like to know the reasons behind every step … and the reasons for doing the experiment in the first place'.

Question 4. Would better understanding of practical work be helpful in understanding the theory parts of the course?

94% of students responded yes while 6% not sure. One student commented '[practical work] shows us the theory proven, therefore reinforcing it in our minds'

A videoed interview with one of the accompanying chemistry teachers discussing the use of LabSkills may be found on the LabSkills website.

‘As a non specialist chemistry trainee teacher I have found this AS Chemistry LabSkills software extremely invaluable. I have encouraged students to use the program while on my placement to gain confidence and practice before a practical assessment. I have found this software package has increased my confidence and understanding in chemistry practicals as well a useful tool for students to increase their confidence.’

Sabahat Kamal, Trainee (PGCE) Chemistry Teacher, University of Bristol

Full evaluation of the role that LabSkills is playing in the training of PGCE chemistry teachers will be assessed nationally later in 2009 and again in 2010 through a series of regional feedback sessions.

Conclusion

Transfer of best practice from tertiary to secondary school is uncommon. A Dynamic Laboratory Manual developed for undergraduate practical chemistry has been adapted for Post-16 level. Preliminary results and feedback show that the package allows students to rehearse effectively for practical sessions at school. In a preliminary trial it was shown that there was a significant impact on cognition and practical skill for post-16 students. In addition to obvious educational benefits to the students, at school these practical sessions are costly in terms of resources and time, and therefore anything that augments the experience is welcomed. Feedback from schools and colleges using this package has been uniformly excellent, highlighting its usefulness for pre-lab but also as a revision aid. Further still, evidence is emerging that practical skill levels are increased.

Readers of *Acta Didactica Napocensia* who wish to trial a full working version of this software just need to contact the author William Heslop to arrange this.

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